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Unsteady Flow Model for Forecasting Missouri and Mississippi Rivers

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UNSTEADY FLOW MODEL FOR FORECASTING MISSOURI AND MISSISSIPPI RIVERS[1]

by

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ABSTRACT

This paper describes development of the Mississippi-Missouri UNET [1] Forecast Model. This project utilizes the UNET unsteady flow model and much of the geometric and flow data developed in the Floodplain Management Assessment study (FPMA) [2]. This effort includes development of a graphical user interface (GUI) reflecting the unique needs of real-time forecasting and design of data protocols for storage, retrieval, presentation and transfer of forecast information from upstream to downstream offices. The data management system uses the Hydrologic Engineering Center's (HEC) Data Storage System [3]. The modeling system is being developed to encompass low flows, routine day-to-day forecasting needs (such as lock and dam operations), as well as the simulation and forecasting of flood events. The status of this effort is described herein.

BACKGROUND

The U.S. Army Corps of Engineers has built and operates a large number of reservoirs, levees, floodways and flow diversion structures in the Mississippi River Basin for flood control and navigation. These projects are operated and maintained by five Corps Divisions in a coordinated manner. The Great Flood of 1993 demonstrated the need for an integrated model to operate and manage flood control projects under a wide-spread storm system covering a geographic region as large as the upper Mississippi River basin. Subsequent to the 1993 flood the Corps committed to development of a model for the following objectives; 1) improve and facilitate communications between Corps offices, other agencies and Corps customers, 2) provide real-time discharge and stage data during flood events to support emergency management activities, 3) provide a means for assessment of impacts due to levee failures, 4) provide displays of areal extent of flooding

[1] Paper presented at RIVERTECH '96 1st International Conference on New/Emerging Concepts for Rivers, September 22-26 1996, Chicago, Illinois.

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for various weather and levee failure scenarios, 5) identify navigation hazards, and 6) provide data for real-time damage assessment.

The Mississippi River Model extends from St. Paul MN to the Gulf of Mexico and is configured as a distributed model. The model consists of a network of seven unsteady flow sub-models; four for the mainstem Mississippi River, two for the Missouri River and one for the Ohio River. It covers thousands of miles of river, including hundreds of inflow points and numerous gauges. The area of the initial application is shown in Figure 1. Many of the experiences and much of the data obtained during the FPMA study have contributed to the forecast model development. Although the emphasis of this work to date has been on flood event forecasting activities, the modeling system is being developed to include low flow, routine day-to-day forecasting needs and project operation activities.

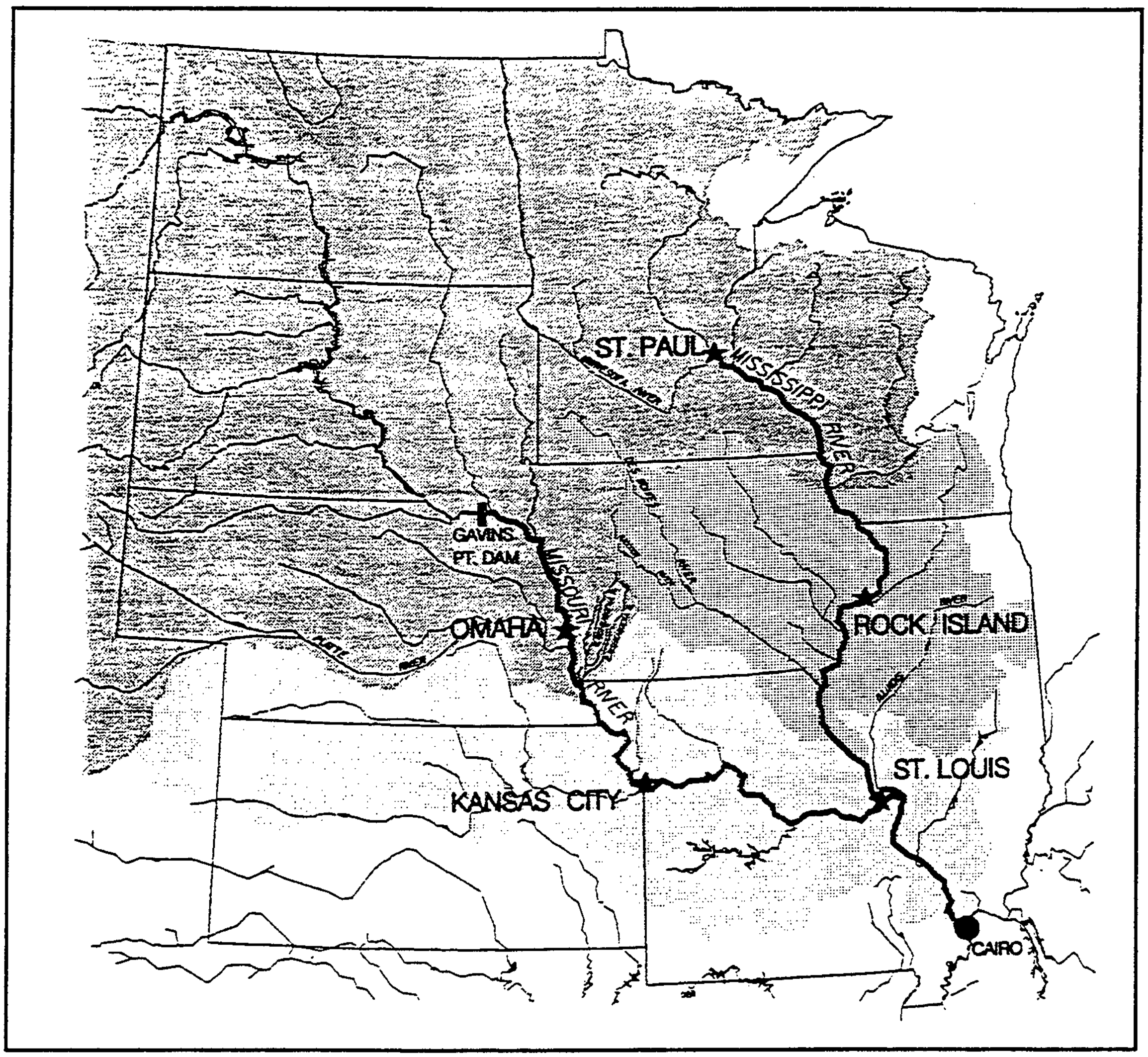

Figure 1. Initial Study Area

THE UNET MODELING SYSTEM

UNET [1] was the primary hydraulic analysis tool used in the FPMA study. It simulates one-dimensional unsteady flow through a network of open channels. One element of open channel flow in networks is the split of flow into two or more channels. For subcritical flow, the division of flow depends on the capacities of the receiving channels. Those capacities are functions of downstream channel geometries and backwater effects. Another element of a flow network is the combination of flow; which is termed the dendritic problem. This is a simpler problem than the flow split because flow from each tributary depends only on the stage in the receiving stream. A flow network that includes single channels, dendritic systems, flow splits, and looped systems such as flow around islands, is the most general problem. UNET has the capability to simulate such a system.

Another capability of UNET is the simulation of storage areas; e.g., lake-like regions that can either provide water to, or divert water from, a channel. This is commonly called a split flow problem. In this situation, the storage area water surface elevation will control the volume of water diverted. This volume, in turn, affects the shape and timing of downstream hydrographs. Storage areas can be the upstream or downstream boundaries of a river reach. In addition, the river can overflow laterally into storage areas over a gated spillway, weir, levee, through a culvert, or via a pumped diversion.

In addition to solving the one-dimensional unsteady flow equations in a network system, UNET has the capability to apply several external and internal boundary conditions, including; flow and stage hydrographs, gated and uncontrolled spillways, bridges, culverts, and levee systems.

To facilitate model application, cross sections are input in a modified HEC-2 [4] forewater (upstream to downstream) format. A large number of river systems have been modeled using HEC-2 and, therefore, those existing data files can be readily adapted to UNET format. Boundary conditions (flow hydrographs, stage hydrographs, etc.) for UNET can be input from any existing HEC-DSS [3] data base. For most simulations, particularly those with large numbers of hydrographs and hydrograph ordinates, HEC-DSS is advantageous because it eliminates the manual tabular input of hydrographs and creates an input file which can be easily adapted to a large number of scenarios. Hydrographs and profiles which are computed by UNET are output to HEC-DSS for graphical display and for comparisons with observed data.

Additional Levee Failure Algorithm

As a result of the 1993 flood on the Missouri River, a new capability for simulating levee failures was added to UNET. The previous approach had been to consider the area behind the levee to be a storage area. That is, it would fill and empty through a levee breach or overtopped area, but not convey water in the downstream direction. For most situations, particularly with lesser floods than that of 1993, this is an adequate assumption. During 1993, however, virtually all of the agricultural levees along the Missouri were overtopped, resulting in significant overbank conveyance. A new algorithm was developed that allows the overbank storage areas to change to conveyance areas (and back) based upon a triggering river flow or stage.

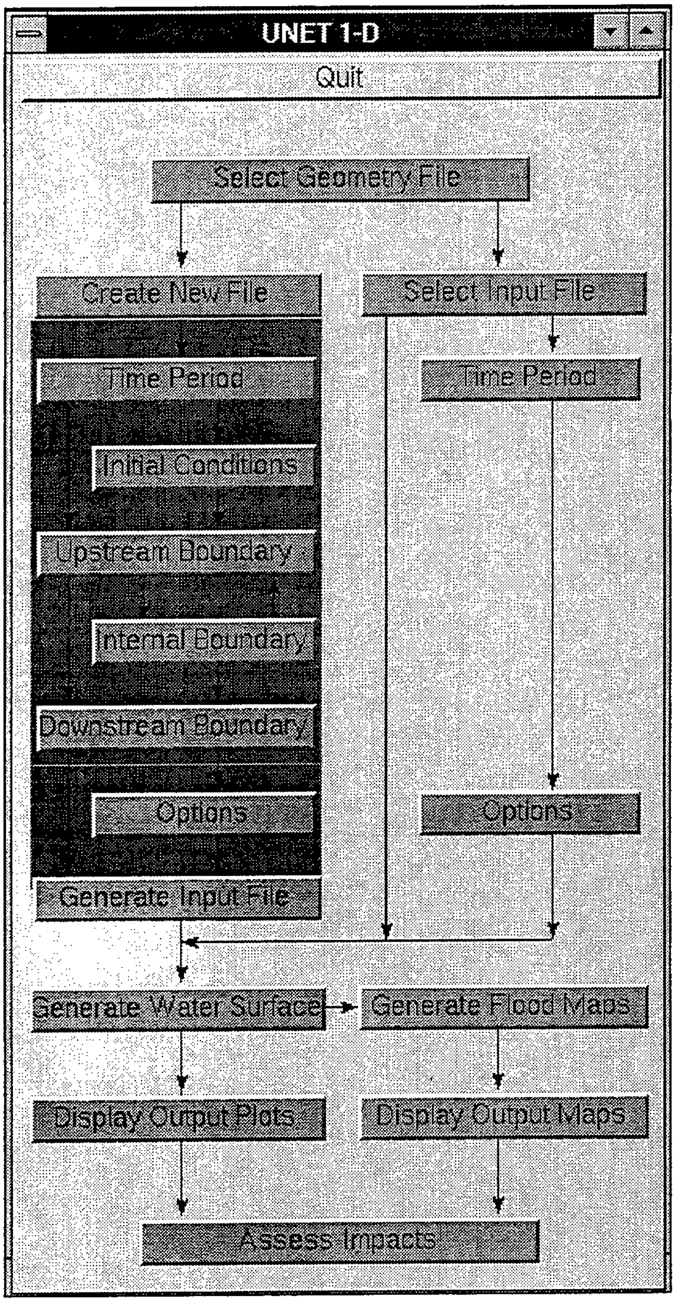

Figure 2. Example Entry Window for UNET

Graphical User Interface

The GUI adapted for the UNET system was developed by the Corps Cold Regions Research and Engineering Laboratory for the Missouri River Division. That work involved management of releases from mainstem Missouri River dams to prevent damage to endangered species habitat. It was primarily a "simulation" application. That interface was expanded to meet the needs for forecasting applications. The enhancements to the interface included; consistent file management, implementation of a UNET hotstart capability, easy time window selection, and interaction with DSS-DSPLAY in a fashion consistent with water control needs. The GUI runs under UNIX. Additional GUI work is underway to more completely integrate UNET into the water control system. Figure 2 shows an entry window. The GUI also interfaces with a geographic information system (GIS) to provide map-based interaction with the data displays. Figure 3 provides an example of such a display. These displays are active in the sense that access to DSS data can be obtained by clicking on the location of interest.

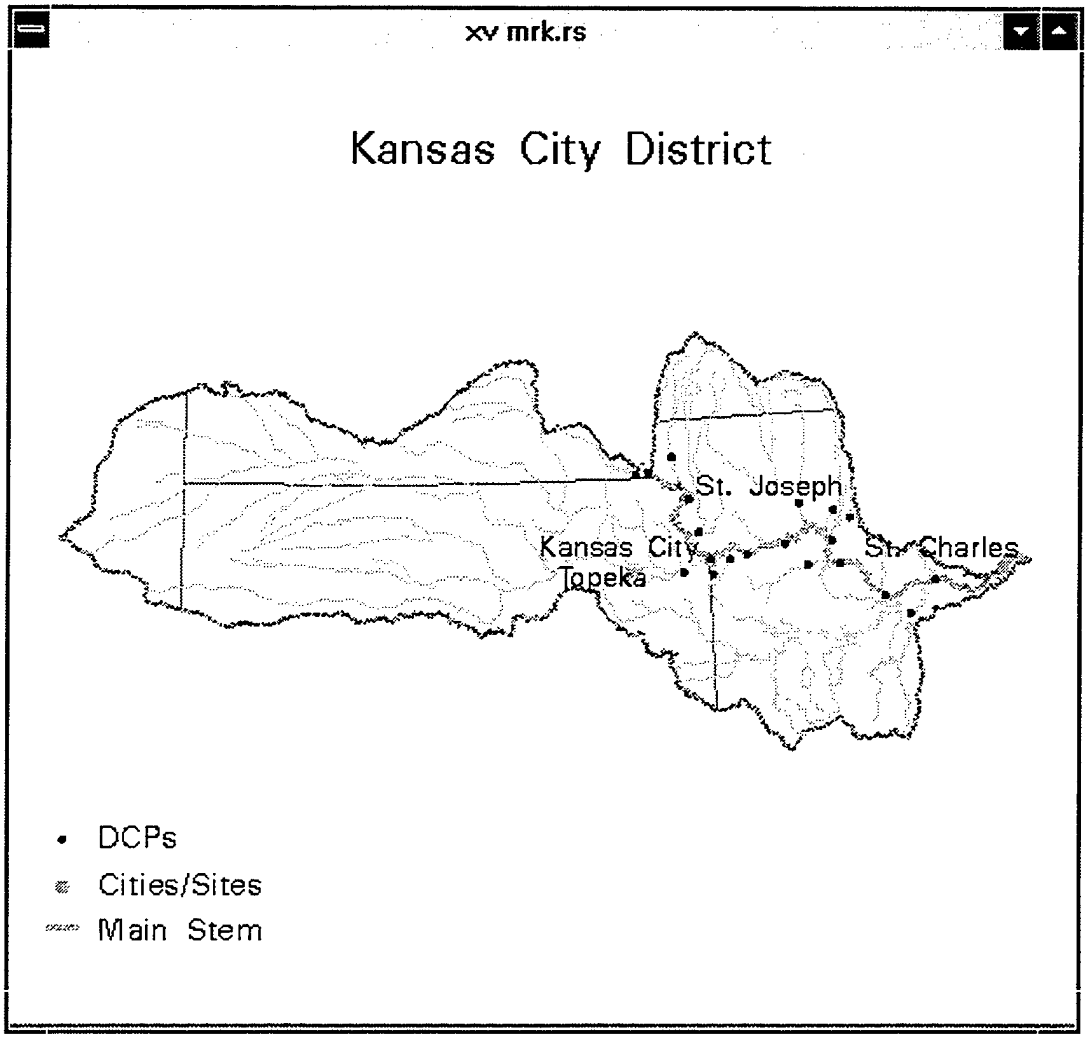

Figure 3. Example Display of a Drainage Basin from the GIS

TWO-DIMENSIONAL CAPABILITY FOR OVERBANK AREAS

An accurate description of combined channel and overland flood flow requires a blend of one (1-D) and two-dimensional (2-D) surface water flow modeling concepts. Two-dimensional computations in a floodplain can range from being fully 2-D and dynamic to consisting of only a few large storage cells with momentum effects completely neglected. For example, through the use of storage cells, UNET provides a method to account for floodplain storage and allows a highly skilled modeler to approximate kinematic floodplain routing through a coarse network of storage cells. A recent evaluation of surface water flow models suggests that it is possible to link 1-D channel flow models, such as UNET, with a 2-D finite volume overland flow model. The overall objective has been to develop the 2-D model and then to formulate, implement, and test a linkage methodology which will allow combined channel and overland flood modeling. This methodology permits 2-D dynamic routing of flows across a floodplain represented by moderate to high resolution finite volume grids. The same linkage methodology could be applied to a number of different 1-D and 2-D routing models. This work is being performed by the Corps Waterways Experiment Station.

The 2-D floodplain routing model is similar to UNET in that conservation of mass and momentum equations are solved. However, for purposes of model flexibility an explicit numerical solution has been selected. The 2-D finite-volume method divides the system into an unstructured grid of cells where stage is defined at the center of the cell. Flows are defined along one-dimensional channels that link the centers of the finite volume cells.

The linkage between UNET and the 2-D floodplain model was evaluated via a series of idealized grid and interior boundary condition tests. These tests demonstrated that the coupling between the two models performed well in a highly stable manner and that flow volume was conserved. Following these tests, a 2-D model grid, Figure 4, was

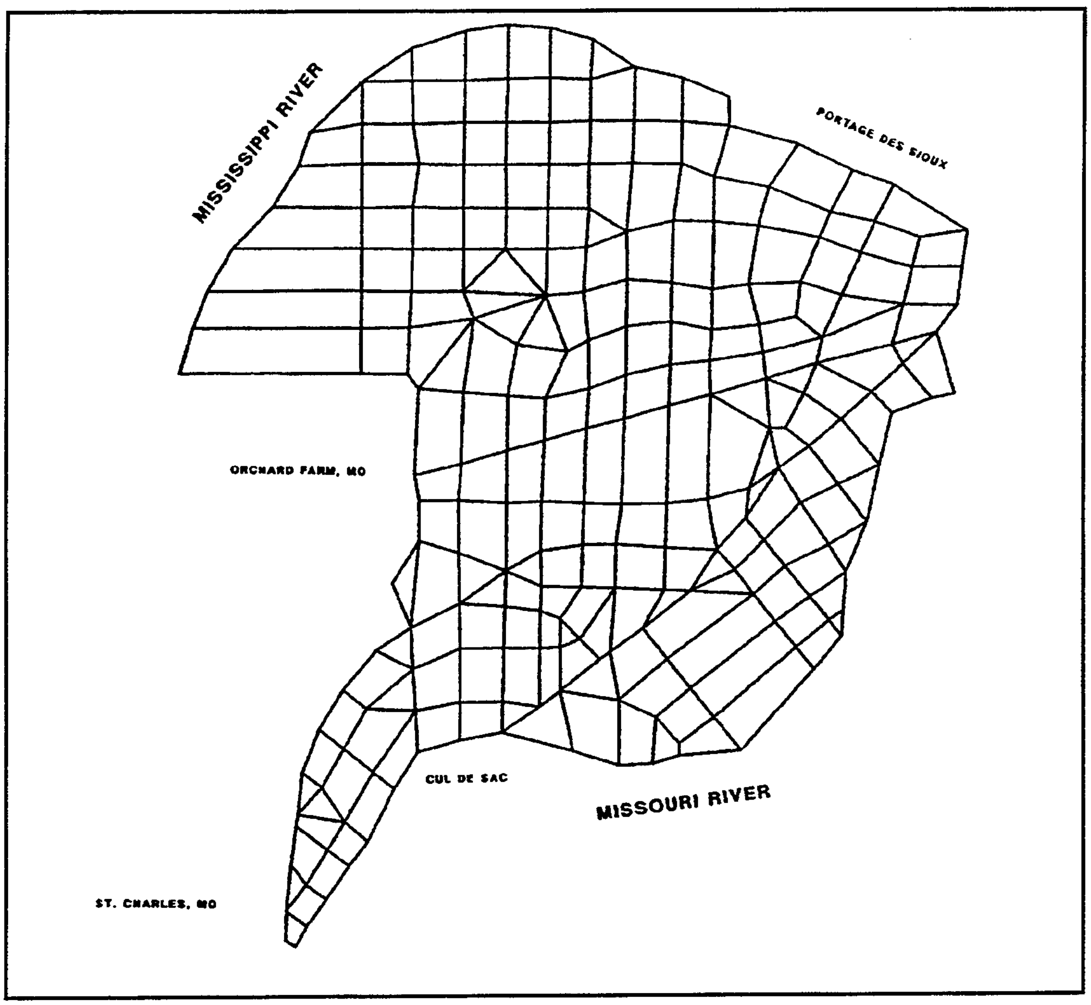

Figure 4. Two-Dimensional Model Grid for Crossover Area

developed representing a portion of St. Charles County, MO, where cross-basin flows from the Missouri River into the Mississippi River occur during large floods. This 2-D model was linked with UNET and used to simulate the 1993 flood event.

DATA REQUIREMENTS

A continuing area of concern is the trade off between the cost of obtaining increased accuracy of topographic data and the accuracy of the results computed from those data. This has been studied and documented for the use of HEC-2, a steady flow model [5]. That study determined that the primary source of uncertainty in computed results was the estimation of energy loss coefficients, not topographic data accuracy using normal surveying standards at that time. Experience with one-dimensional unsteady flow models, such as UNET, has confirmed and expanded that conclusion. It is important, in the application of an unsteady flow model, that storage as well as conveyance be properly represented. This requires accurate definition of the conveyance and the flow-controlling elevations and locations (e.g., levees, weirs, etc.). Ground elevations in storage areas such as overbanks and leveed areas are not as critical, if the volumetric capacity of those areas is correct. Information based on topographic maps with 1.5m (5 ft.) contours is usually adequate for overbank areas for systems with broad floodplains. When applying a two-dimensional flow model, however, the ground topography becomes more important, particularly in areas of little vertical relief. It was decided that 0.5m (2 ft.) vertical resolution was needed in the cross-over area between the Missouri and Mississippi Rivers for reliable two-dimensional modeling. This requirement depends on the relationship between water depth and bed elevation changes. When applying any of these hydraulic modeling approaches, one must be aware that there is substantial uncertainty in past inflows to the system as well as the forecasted inflows, all of which will influence the accuracy of the computed results.

CALIBRATION

Model parameters were adjusted to improve reproduction of stages for the 1993 flood. While this effort focused primarily on modifying energy loss coefficients (roughness values) in some areas additional geometric or flow data were needed. During the floodings of June 1995 and May 1996 the Rock Island and St. Louis Districts successfully utilized the previously calibrated UNET data in a real time forecasting situation.

A need for improved forecasting of flows from ungauged areas has been identified. This need is being addressed through the development of improved hydrologic models which parallels the development of HEC's Hydrologic Modeling System [6].

OPERATION OF THE FORECASTING SYSTEM

Forecast operation of the initial UNET forecasting modeling system involves three Districts at this time; Rock Island, Kansas City, and St. Louis (Fig. 1). During day-to-day forecasting operation, upstream Districts will develop their forecasted flows and stages at a selected data transfer point and electronically provide these data to the downstream District; which will, in turn, use these hydrographs as upstream boundary conditions.

In general, the data transfer location (i.e., the passing of the upstream forecast to the downstream office) is within the upstream District. The downstream boundary condition used for the upstream District model is located at that District's downstream geographic boundary. The overlap area minimizes the influence from uncertainties in the downstream boundary condition data on the computed results at the data transfer location. Within the overlap area, both Districts use the same river geometry. Forecasting local inflows within the overlap areas, if any, is done by the upstream District.

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13. ABSTRACT *(Maximum 200 words)*

The objective of this paper is to present methods that can be used to estimate the quantity and gradation of sediment produced from a watershed. These values are necessary for mobile boundary hydraulic modeling and other sedimentation studies. These quantities are needed for designing flood control channels, estimating sediment deposition in reservoirs or navigation channels, and evaluating the sedimentation impacts of proposed projects or land use modifications. Considerable information is available for the estimation of sediment yield from a watershed. These methods use both empirical techniques and land surface erosion theory. The same is true for quantifying sediment transport and sorting processes in rivers. This paper focuses on procedures for using land surface erosion computations to develop the inflowing sediment load for a river sedimentation model, specifically, HEC-6.

The limitations of currently available methods and their ranges of applicability are presented and procedures for evaluating computed results for watershed erosion and sediment transport modeling are described. Included herein are the results of an assessment of numerical models for the prediction of land surface erosion. It was concluded from this assessment that these models have not yet evolved from the experimental/developmental phase to routine engineering use. Therefore, this paper presents a suggested strategy for the use of several traditional methods of computation of land surface erosion to prepare inflowing sediment loads for the operation of HEC-6.

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